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Quantum Electrodynamics (QED) represents thus far one of the greatest theoretical achievements in modern physics, able to elegantly combine electromagnetism, quantum mechanics, and special relativity into a unified theory. Its predictions have been tested to a high degree of precision in relatively low field intensities but, thus far, little is experimentally known about the behaviour of quantum systems in ultra-high fields. QED effects are dominant if these fields are comparable to the critical field (also known as the Schwinger field): $E_S \sim 1.3\text{x}10^{18}$ V/m. At these field intensities, exotic phenomena will occur, such as stochastic photon emission [1], electron-positron pair production even in a classical vacuum [2], and strong radiation reaction [3].

Even though electromagnetic fields of this nature are expected to be present around massive astrophysical objects (see, for instance, [4]), experimental studies have been extremely limited, only exploiting strong crystalline fields [5] or ultra-relativistic electron beams in accelerators [6].

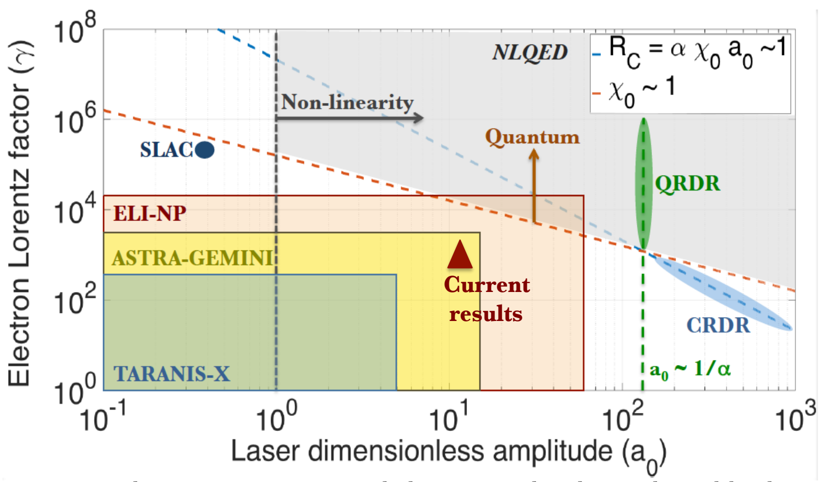


**Fig. 1** Electron energies and laser amplitudes achievable by different laser systems: ELI-NP (red rectangle), Astra-Gemini (yellow), and TARANIS-X (green) compared with different physical regimes. The red dashed line corresponds to the critical field in the rest frame of the electron. The grey-shaded area shows regions of pure non-linear QED. The blue circle and the red triangle relate to the SLAC experiment [6], and our Previous Work, respectively.

However, the fast-paced development of laser technology and laser-driven particle acceleration [7] is finally opening up the possibility of experimentally studying non-linear (i.e. high-field) QED. Existing lasers now can produce conditions very close to the critical field (yellow box in Fig. 1) with near-term facilities under construction expected to overcome it (red box in Fig. 1).

In a recent experimental campaign at the Astra-Gemini laser we achieved conditions where electrons feel, in their rest frame, an electric field equal to 0.2 $E_S$ (red triangle in Fig.1). This was achieved exploiting a head-on collision of an intense laser pulse ($I_L \sim 2\text{x}10^{20}$ $\text{Wcm}^{-2}$) with a laser-driven ultra-relativistic electron beam (maximum Lorentz factor of $\gamma_L \sim 3500$). Clear evidence was found, for the first time, of strong radiation reaction with a 40% electron energy loss in 40 femtoseconds of laser duration [8]. This talk will present these results, together with a discussion of current developments in order to fully access experimentally, for the first time, regimes of purely non-linear QED.

## References


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